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Effects of feeding processed corn stover and distillers grains on growth performance and metabolism of beef cattle

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ABSTRACT: Objectives were to evaluate the effects of replacing corn in feedlot finishing diets with processed corn stover (CS), processed by various combinations of chemical and physical methods, and modified wet distillers grain with solubles (MWDGS) on growth performance, carcass characteristics, digestibility, and ruminal metabolism of cattle. Corn stover was physically processed (ground or extruded) and chemically processed with alkaline agents (CaO and NaOH) to reduce the crystallinity of the lignocellulosic structure. In Exp. 1 steers (n = 18, initial BW = 385 ± 32 kg) and heifers (n = 41, initial BW = 381 ± 27 kg) were allotted to 1 of 5 dietary treatments: 1) 55% dry, cracked corn, 35% MWDGS, 5% vitamin-mineral supplement, and 5% untreated ground CS (**CON**), 2) CS treated with 5% CaO (DM basis) and stored in an Ag-Bag (BGCS), 3) CS treated with 5% CaO (DM basis) and extruded (5 EXCS), 4) CS treated with 4% CaO and 1% NaOH (DM basis) and extruded (4,1 EXCS), or 5) CS treated with 3% CaO and 2% NaOH (DM basis) and extruded (3,2 EXCS). Extruded CS was hydrated to 34% moisture, then an additional 16% water was added, as a solution carrying CaO or NaOH or both, via a calibrated pump during processing through a dual-shafted encased extruder (Readco Kurimoto Continuous Processor, York, PA) with the desired exiting temperature of 76.7°C ± 2.8°C. All treated CS diets contained 20% CS and 40% MWDGS (DM basis) to replace 20% corn when compared to CON. There were no effects ($P \geq 0.20$) of dietary treatment on ADG, G:F, 12th-rib back fat, marbling score, LM area, or yield grade. However, cattle fed CON had increased ($P = 0.02$) DMI compared to cattle fed the treated CS diets. In Exp. 2, using the same diets as fed in Exp. 1, ruminally cannulated steers (n = 5; initial BW = 417 ± 21 kg) were fed for 90% of ad libitum intake in a 5 × 5 Latin square design. Apparent digestibility of NDF and ADF increased ($P < 0.01$) when cattle were fed treated CS diets compared with CON, regardless of the treatment applied. Ruminal pH was reduced ($P = 0.02$) in cattle fed BGCS from 0 to 6 h postfeeding compared with cattle fed all other diets. Cattle fed the treated CS diets had the greatest ($P < 0.01$) mean acetate concentrations, which increased ($P = 0.01$) total VFA concentrations. Replacing a portion of the corn with treated CS in feedlot diets containing MWDGS increased fiber digestibility without affecting feedlot cattle gain, efficiency, marbling score, or LM area.

Key words: calcium oxide, cattle, corn stover, digestibility, distillers grains

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INTRODUCTION

Corn stover (**CS**) is a readily available alternative feedstuff (Graham et al., 2007). In combination with modified wet distillers grains with solubles (**MWDGS**), CS has been used to replace corn in beef finishing diets (Lardy, 2007). However, CS is poorly digested (Klopfenstein, 1978), and its utility in cattle diets may be improved by processing (Shreck et al., 2012a).

Physical and chemical treatments have been shown to improve digestibility of CS (Burdick and Sullivan, 1963; Kerley et al., 1985; Sewell et al., 2009). Shreck et al. (2013b) showed that cattle fed diets containing coproducts and treated crop residues have feed efficiencies similar to those of cattle fed corn-based diets. Because of availability, ease of application, and

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cost, CaO has become a suitable chemical pretreatment for CS (Russell et al., 2011; Shreck et al., 2012a). Additionally, Sewell et al. (2009) demonstrated that extruding CS with CaO improved NDF digestibility when compared with unprocessed CS; however, Chaudhry (2000) stated that NaOH increases fiber digestibility of crop residues to a greater extent than CaO.

Optimal combinations of physical and chemical processing to maximize the digestibility of CS and the ability of CS to replace 20% corn in the diet are currently not known. We hypothesized that cattle fed diets containing CaO-treated CS at 20% of the diet DM would perform similarly to cattle fed a corn-based control diet during the finishing phase. Additionally, we hypothesized that treating CS with combinations of alkaline agents would better increase digestibility and ruminal pH than a single alkaline agent alone. Therefore, the objectives of these 2 experiments were to evaluate the effects of replacing 20% corn in feedlot finishing diets with processed CS, processed by various combinations of chemical and physical methods, and MWDGS on growth performance, carcass characteristics, digestibility, and ruminal metabolism of cattle.

MATERIALS AND METHODS

Animals in this trial were managed according to guidelines recommended in the Guide for the *Care and Use of Agriculture Animals in Agriculture Research and Teaching* (Federation of Animal Science Societies, 2010). Experimental procedures were approved before the initiation of this trial by the University of Illinois Institutional Animal Care and Use Committee.

Experiment 1

Animals and Diets. Angus × Simmental crossbred steers (n = 18, initial BW = 385 ± 32 kg) and heifers (n = 41, initial BW = 381 ± 27 kg) were placed on trial at the University of Illinois Beef Cattle and Sheep Field Laboratory in Urbana. Cattle were housed in total confinement in 4.9 × 4.9 m pens on concrete slatted floors covered with rubber matting (Ani-mat Inc., Sherbrooke, QC, Canada).

Steers and heifers were randomly assigned to 1 of 5 diets (Table 1): 1) 55% dry, cracked corn, 35% MWDGS, 5% vitamin-mineral supplement, and 5% untreated ground CS (**CON**), 2) CS treated with 5% CaO (DM basis) and stored in an Ag-Bag (**BGCS**; Ag-Bag, A. Miller-St. Nazianz Inc., St. Nazianz, WI), 3) CS treated with 5% CaO (DM basis) and extruded (**5 EXCS**), 4) CS treated with 4% CaO and1% NaOH (DM basis) and extruded (**4,1 EXCS**), or 5) CS treated with 3% CaO and 2% NaOH (DM basis) and extruded (**3,2 EXCS**). All treated CS diets contained 35% dry, cracked corn and 5% vitamin-mineral supplement (DM basis). Treated 20% CS and 40% MWDGS replaced 20% corn grain and ensured that diets remained isonitrogenous. Corn grain was cracked to achieve the targeted 3 to 4 particles per kernel. Corn replacement diets contained 20% and 40% (DM basis) of CS and MWDGS, respectively. Diets were mixed in a 9.34 m^2 reel mixing wagon (Knight Reel Auggie 3130, Kuhn Agricultural Machinery, Brodhead, WI) and delivered once daily. Cattle were fed for ad libitum intake, i.e., approximately 0.25 kg of refusal per animal when feed delivery was determined for the day. The total mixed ration (**TMR**) samples were collected weekly at the time of feeding from the feed bunks. At the time of collection, approximately 454 g were sampled from each bunk, composited, and mixed by hand. After mixing, 10% of the composited sample was retained and frozen at −20°C for later compositing. After the trial ended, the 11 weekly

Table 1. Diets and analyzed nutrient composition of diets fed to cattle in Exp. 1

	Dietary treatment[1]				
Item	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS
Ingredient, % DM					
MWDGS	35	40	40	40	40
Dry-cracked corn	55	35	35	35	35
Corn stover	5	20	20	20	20
Supplement[2]	5	5	5	5	5
Analyzed composition, % DM					
NDF	17.78	22.34	22.78	26.53	23.59
ADF	8.87	14.79	14.03	16.50	13.32
CP	14.00	14.51	14.29	14.21	14.51
Fat	5.01	4.83	4.57	4.52	5.00
Ca	0.90	1.67	1.73	1.23	1.13
P	0.41	0.42	0.40	0.42	0.42
S	0.28	0.31	0.32	0.31	0.32
Ash	5.33	8.66	9.20	8.87	8.27

[1]CON = 55% corn and 5% untreated ground corn stover on DM basis (corn control); BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO; 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded; 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded; 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

[2]Supplement formulated to contain (DM basis) ground corn, 60.76%; limestone, 34.19%; swine trace mineral salt, 2.23% (85% salt, 2.57% Fe, 2.86% Zn, 5,710 mg Mn/kg, 2,290 mg Cu/kg, 100 mg I/kg, 85.7 mg Se/kg); ADEK vitamin mix, 0.22% (680,400 IU vitamin A/kg, 68,040 IU vitamin D_3/kg, 9,072 IU vitamin E/kg, 453.5 IU vitamin K/kg, 3.63 mg vitamin B_{12}/kg, 907.2 mg riboflavin/kg, 2,494.8 mg D-pantothenic acid/kg, 3,402 mg niacin/kg, 29,461 mg choline/kg); Tylan 40, 0.25% (88 g tylosin/kg DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg DM, Elanco Animal Health); Thiamine 40, 0.21% (88 g thiamine mononitrate/kg DM, ADM Alliance Nutrition Inc., Quincy, IL); copper sulfate, 0.11%; fat, 1.69%.

samples were thawed, composited into 1 final sample, and mixed by hand. Then, 10% of the final composited TMR sample was retained for nutrient analysis.

Treatment of Corn Stover for Treated Corn Stover Diets. Round bales (approximately 544 kg) of CS were delivered to the University of Illinois Beef Cattle and Sheep Field Laboratory and stored under roof in an open-sided shed before processing. Corn stover was baled in September 2010 and stored under roof until being delivered to the University of Illinois in March 2011. Bales of CS were ground using a tub grinder (Haybuster Big Bite H-1000 series, Agricultural Products DuraTech Industries International Inc., Jamestown, ND) through a 2.54-cm screen and stored in a commodity bay for no more than 7 d before chemical processing. Corn stover was then loaded into a mixing wagon (Knight Reel Auggie 3130, Kuhn Agricultural Machinery) and hydrated to 50% moisture with Urbana city water. Calcium oxide (Microcal OF 200, Mississippi Lime Company, St. Louis, MO) was added at a concentration of 5% (DM basis) to the hydrated CS and mixed for 15 min to ensure complete incorporation. The average pH of CaO-treated CS before bagging was 10.9. Treated corn stover was then bagged in an Ag-Bag (A. Miller-St. Nazianz Inc.) and anaerobically stored for a minimum of 21 d before feeding. For extruded CS, CS was loaded into a smaller, custom-built, retrofitted feed mixing wagon with a hydraulic-powered conveyer belt (E Rissler Mfg. LLC, New Enterprise, PA) and hydrated to 34% moisture. The 34% hydrated CS was unloaded from the mixing wagon onto a conveyor belt, and then 5% CaO, 4% CaO to 1% NaOH, or 3% CaO to 2% NaOH (5% DM basis) and an additional 16% water were added as a solution via a calibrated pump during processing through a dual-shafted encased extruder (Readco Kurimoto Continuous Processor, York, PA). Two individual pumps were used to transfer the CaO and NaOH solutions from separate storage tanks. Both solutions were mixed fresh daily. Quality control of processed CS was monitored by regulating the retention time (6 to 10 s) to achieve the desired exiting temperature (76.7°C ± 2.8°C). Output of the processor was 270 kg/h. After processing, extruded corn stover was aerobically stored in a commodity bay for 8 ± 6 d before feeding. The pH of processed CS immediately after processing was 10.5 ± 1.0, and after storage, the pH of processed CS was 10.1 ± 0.8.

Feedlot Performance and Carcass Data Collection. Steers and heifers were weighed on 2 consecutive days at the beginning of the trial to determine initial BW. On d 1, steers and heifers were implanted with Component TE-S and TE-H, respectively, with Tylan (Elanco, Greenfield, IN), and weights from d 0 were used to randomly assign steers and heifers to their designated mixed-gender treatment pens. Body weights were recorded on d 0, 1, 14, 28, 42, 56, and 70. Cattle were weighed in a hydraulic squeeze chute (Flying W Livestock Equipment, Watonga, OK) with a Tru-Test XR 3000 (Tru-Test Inc., Mineral Wells, TX) weight recording system. Individual feed intake was measured for 75 d using the GrowSafe (GrowSafe Systems Ltd., Airdrie, AB, Canada) automated feed intake monitoring system. Steers and heifers were deemed ready to ship after visual appraisal estimated that cattle had sufficient finish to grade Low Choice or better.

All cattle were shipped 301 km and slaughtered at a commercial abattoir. Hot carcass weights were recorded on the day cattle were slaughtered. Carcasses were then chilled for 24 h at −4°C. After a 24-h chill, carcasses were ribbed between the 12th and 13th ribs to determine 12th-rib back fat thickness (**BF**), LM area, and marbling score (**MS**) via USDA grading cameras. Kidney, pelvic, and heart fat was determined by trained USDA personnel. Yield grade (**YG**) was calculated using the USDA equation (USDA, 1997). Final BW was calculated by adjusting HCW to a common dressing percentage (**DP**) of 62.0. This final BW was then used to calculate ADG and G:F.

Sample Analysis. Composited TMR diet samples were freeze-dried (FreeZone12, Labconco, Kansas City, MO) and ground with a Wiley mill (Arthur H. Thomas, Philadelphia, PA) to pass through a 1-mm screen. Composited, freeze-dried TMR samples were analyzed to determine nutrient composition. Analyses included DM (105°C) via a forced-air drying oven (Heratherm OMS100, Thermo Fischer Scientific Inc., Waltham, MA), ash and OM (500°C for 20 h; HotPack Muffle Oven, model 770750, HotPack Corp., Philadelphia, PA), NDF (Ankom Technology, method 6; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), ADF (Ankom Technology, method 5; Ankom200 Fiber Analyzer, Ankom Technology), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (Ankom Technology, method 2; AnkomXT10 Extraction System, Ankom Technology). Inductively coupled plasma electrophoresis was used to determine macrominerals after perchloric acid digestion (AOAC, 1988).

Statistical Analysis. Feedlot performance and carcass characteristics data were analyzed in a completely randomized design. Because of the individual animal intake data collected, animal served as the experimental unit. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze all performance and carcass characteristics. The initial BW of cattle fed the 3,2 EXCS diet was greater ($P < 0.05$) than that of cattle fed 4,1 EXCS and BGCS. Therefore, initial BW was used as a covariate to analyze all feedlot performance and carcass characteristics. Degrees of freedom were

Table 2. Diets and analyzed nutrient composition of diets fed to steers in Exp. 2

	Dietary Treatment[1]				
Item	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS
Ingredient, % DM basis					
MWDGS	35	40	40	40	40
Dry-cracked corn	55	35	35	35	35
Corn stover	5	20	20	20	20
Supplement[2]	5	5	5	5	5
Analyzed composition, % DM basis					
NDF	22.20	25.13	26.44	26.12	27.01
ADF	10.55	15.75	16.38	16.29	14.82
CP	14.68	14.71	14.62	14.74	14.78
Fat	4.90	4.37	4.47	4.69	4.86
Ca	0.56	1.64	1.68	1.25	1.13
P	0.43	0.41	0.42	0.44	0.43
S	0.28	0.32	0.33	0.33	0.31
Ash	4.66	7.88	8.43	8.09	7.77

[1]CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control). BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO. 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded. 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded. 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

[2]Supplement formulated to contain (DMB): ground corn, 60.76%; limestone, 34.19%; swine trace mineral salt, 2.23% (85% salt, 2.57% Fe, 2.86% Zn, 5,710 mg Mn/kg, 2,290 mg Cu/kg, 100 mg I/kg, 85.7 mg Se/kg); ADEK vitamin mix, 0.22% (680,400 IU Vit A/kg, 68,040 IU Vit D3/kg, 9072 IU Vit E/kg, 453.5 IU Vit K/kg, 3.63 mg Vit B12/kg, 907.2 mg riboflavin/kg, 2494.8 mg d-pantothenic acid/kg, 3402 mg niacin/kg, 29,461 mg Choline/kg); Tylan 40, 0.25% (88 g tylosin/kg of DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg of DM, Elanco Animal Health); Thiamine 40, 0.21% (88g thiamine mononitrate/kg of DM, ADM Alliance Nutrition, Inc., Quincy, IL); copper sulfate, 0.11%; fat 1.69%.

adjusted using the Kenward-Roger method. Means were separated using the LSMEANS command in SAS, and differences were declared significant at $P \leq 0.05$.

Experiment 2

Animals and Diets. Angus × Simmental steers ($n = 5$; initial BW = 417 ± 21 kg) were surgically fitted with rumen cannulae 4 mo before the initiation of this study. Steers were gradually adapted over 3 wk from a forage to a concentrate diet containing 40% MWDGS, 35% dry, cracked corn, 20% untreated ground CS, and 5% vitamin-mineral supplement (DM basis). Steers were randomly assigned to 1 of the 5 treatment diets from Exp. 1 (Table 2). Steers were fed in a 5 × 5 Latin square design for 90% of ad libitum intake. Diets were individually mixed in a paddle mixer (model SPC-2436, Marion Mixers Inc., Marion, IA) daily before feeding at 0900.

Steers were housed in a climate-controlled barn located at the University of Illinois Beef Cattle and Sheep Field Laboratory in individual metabolism stalls. Stalls measure 1.5 × 2.4 m and are constructed of stainless-steel tubing with dense rubber flooring. Stall floors were scraped and washed at least twice daily, once before the morning feeding and once in the afternoon.

Sampling and Analysis. Each period of the Latin square was 14 d. The first 9 d of each period allowed for dietary adaptation, similar to the methods of Baumann et al. (2004). Following the adaptation phase, 5 d of intake data and fecal collection were performed to determine total tract apparent digestibility. On the last day of the fecal collection period, ruminal fluid was sampled and analyzed for VFA concentration and pH, as described below. At the conclusion of each period, approximately 8 L of rumen fluid from the steer on the current diet were transferred to the next steer on that diet in an attempt to acclimate the rumen to the new diet.

Individual ad libitum feed intakes were determined and recorded during the adaptation phase. During the 5-d collection phase, feed was offered at 90% of the average ad libitum intakes during the adaptation phase. During the 5-d collection phase, 100 g of the daily ration for each diet were sampled and frozen at −20°C for later analysis. In addition, individual feed ingredients were composited across periods and and saved for later analysis (Table 3). To measure fecal output, 5 stainless steel pans were placed behind the metabolism stalls. Pans were placed immediately after feeding on d 10 for 120 h of fecal collection. Every 24 h, pans were weighed back, and 10% of the total fecal weight was subsampled and frozen. At the conclusion of the study, frozen fecal subsamples were thawed and composited for nutrient analysis to determine nutrient digestibility. Composited feed and fecal samples were freeze-dried (FreeZone[12], Labconco) and ground with a Wiley mill (Arthur H. Thomas) to pass through a 1-mm screen. Procedures of proximate analysis were as described in Exp. 1.

To determine the effects of diets on ruminal pH, ruminal fluid was collected at 0, 1.5, 3, 6, 9, 12, and 18 h postfeeding. Immediately after collection, ruminal contents were filtered through 2 layers of cheese cloth, and pH was recorded (Metler Toledo FE20, Metler Toledo Inc., Columbus, OH). To determine VFA concentration, a subsample of strained ruminal contents was saved at 0, 3, and 6 h postfeeding. Approximately 75 mL of filtered rumen fluid were then acidified with 75 mL of 2 N HCl, mixed, and refrigerated for 12 h at 4°C. After 12 h of refrigeration, 4 mL of rumen fluid and 1 mL of 25% HPO_3 were pipetted into centrifuge tubes and allowed to stand for 30 min. Samples were then centrifuged (model J2-21, Beckman Instruments Inc., Brea, CA) for 20 min at 20,000 × g at 4°C, and the supernatant was filtered through 0.45-µm filters and transferred into 1.5-mL microfuge tubes. Samples

Table 3. Effects of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on growth performance and carcass characteristics of cattle in Exp. 1

	Dietary treatment[2]						
Item[1]	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS	SEM	*P*-value
n	12	12	11	12	12	—	—
Initial BW, kg	386[a,b]	377[b]	385[a,b]	364[b]	401[a]	8.13	0.03
Final BW,[3] kg	478	472	473	468	479	7.44	0.84
ADG, kg	1.27	1.19	1.21	1.15	1.29	0.10	0.84
DMI, kg	8.08[a]	6.86[b]	6.85[b]	6.87[b]	7.11[b]	0.32	0.02
G:F	0.157	0.171	0.178	0.165	0.180	0.010	0.49
HCW, kg	297	293	294	290	297	4.61	0.84
Back fat, cm	1.11	0.92	0.80	0.99	0.86	0.10	0.20
LM area, cm^2	77.69	79.98	79.88	78.14	75.10	2.46	0.62
KPH, %	2.2	2.1	2.0	2.1	2.0	0.1	0.42
Yield grade[4]	2.7	2.3	2.2	2.5	2.4	0.2	0.26
Marbling score[5]	497	459	459	424	463	29	0.53

[a,b]Means within the same row without common superscripts differ ($P \leq 0.05$).

[1]Initial BW was used as a covariate for all parameters.

[2]CON = 55% corn and 5% untreated-ground corn stover on DM basis (corn control); BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO; 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded; 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded; 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

[3]Final BW calculated as HCW/0.62 (common dressing percentage).

[4]Yield grade calculated using the USDA equation (USDA, 1997).

[5]Marbling score: 400 = Small00, 500 = Modest00, 600 = Moderate00.

were then frozen overnight at −20°C and thawed the next morning to be centrifuged in a microfuge (model 5418, Eppendorf North America, Hauppauge, NY) for 10 min. The supernatant was then pipetted to gas chromatography (**GC**) vials. The GC vials were stored at 2°C until GC (model 5890 Series II GC with FID detector, Agilent GC, Santa Clara, CA) was performed to determine VFA concentration. The column used was custom packed (1.83 m × 4 mm, 10% SP-1200/1% H3PO4 on 80/100 Chromosorb W AW support; oven temperature was 125°C, inlet temperature was 175°C, and outlet temperature was 180°C) to ensure peaks were defined within the analysis.

Statistical Analysis. The experimental design was a 5 × 5 Latin square. Steer served as the experimental unit. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) with repeated measures to test the effects of time and time × treatment interactions on pH and VFA concentration. The covariance structure, compound symmetry, was chosen on the basis of the lowest Bayesian information criterion. The subject was the steer nested within period, and degrees of freedom were adjusted using the Kenward-Roger method. Means were separated using the LSMEANS command in SAS. If a significant time × treatment interaction was observed, the SLICE procedure in SAS was used to separate treatment effects within hour. Significance was declared at $P \leq 0.05$. Trends were discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Experiment 1

There were no treatment effects ($P \geq 0.49$) on final BW, ADG, or G:F (Table 4). An average 16.7% greater ($P = 0.02$) DMI was observed for cattle fed CON compared with cattle fed all other diets. Similar to our results, previous research conducted by Russell et al. (2011) reported a 6.5% greater ($P < 0.05$) DMI for cattle consuming a control diet containing 70% corn grain and 20% MWDGS (DM basis) compared with cattle consuming a treated CS diet (5% CaO, DM basis) that was fed at 20% (DM basis). The increased DMI observed for steers and heifers fed CON did not result in differences ($P \geq 0.49$) in ADG or G:F among dietary treatments. These findings are contradictory to previous reports. Russell et al. (2011) found that cattle fed 20% CaO-treated CS (5%, DM basis) and 40% MWDGS (DM basis) had a 5% improvement ($P < 0.05$) in G:F when compared with cattle fed the control diet (70% corn grain, 20% MWDGS; DM basis). They attributed the G:F increase to a 5% reduction ($P < 0.05$) in DMI and no differences in ADG for cattle fed CaO-treated CS compared with those fed the control diet. Lack of change in final BW for CaO-treated CS diets noted in this trial does agree with the findings of Shreck et al. (2012a,b), but it again contradicts the observations of Russell et al. (2011) and Duckworth et al. (2014). Russell et al. (2011) and Duckworth et al. (2014) reported decreased final BW (by 1.2% and 2.9%, respectively) in steers fed CaO-treated CS fed at 20% (DM basis) compared with those fed nontreated CS at the same inclusion. These authors attribute the observed reductions in final BW to the decrease in ADG for cattle fed treated CS. The reduction in BW reported by Duckworth et al. (2014) is of particular interest. Unlike in the previously discussed study by Russell et al. (2011), Duckworth et al. (2014) fed the same amount (40% DM basis) of MWDGS and CS among dietary treatments during the finishing phase; however, their control diet differed from that of the present trial as it contained 20% CS (DM basis) that was untreated, hydrated to 50% moisture, and anaerobically stored, whereas the present trial compared treated CS to a corn-based control. The conflicting results for final BW, ADG, and DMI among trials testing CaO-treated CS require further research. However, much of the variation in the trials to date may be due to the use of varying control diets, which makes comparison across studies challenging. In the present study, the objective was to test the ability of feeding various treated-CS diets with MWDGS to replace 20% of the corn in feedlot diets. Thus, an attempt was made to keep these diets isonitrogenous via changing the MWDGS inclusion. Among the treated-CS diets, however, the fiber fractions varied, even though the dietary inclusion of CS and MWDGS were held constant. In particular, these variations led to approximately 3% units more hemicellulose in the diets containing combinations of CaO- and NaOH-treated CS vs. the CaO-treated CS diets alone. More recent studies reported above have focused predominantly on the use of CaO treatment for CS, but our data suggest CaO may not be the best chemical to liberate lignocellulosic bonds; this will be discussed more in Exp. 2.

There were no treatment effects ($P \geq 0.20$) for BF, LM area, KPH, YG, or MS (Table 3). In agreement with the current study, Shreck et al. (2012a) indicated that there were no differences ($P > 0.05$) in MS, YG, BF, or LM area for steers fed 20% treated CS (5% CaO, DM basis), 40% WDGS, and 36% dry-rolled corn (DM basis) compared with cattle fed 46% dry-rolled corn, 40% WDGS, and 10% of untreated crop residues (equal parts wheat straw, corn stover, and ground corn cobs; DM basis). Furthermore, Shreck et al. (2012b) reported no MS, YG, BF, or LM area differences ($P > 0.05$) in cattle fed 36% corn grain, 20% treated CS (5% CaO, DM basis), and 40% MWDGS(DM basis) compared with cattle fed 50% corn grain, 5% untreated CS, and 40% MWDGS (DM basis). These 2 studies investigated the effects of particle size and crop residue effects in diets containing corn and coproduct fed to finishing cattle; CS was treated in a similar manner to BGCS in our study. However, carcass data from the current study conflict with the findings of Duckworth et al. (2014). These authors reported a tendency ($P \leq 0.08$) for cattle fed CaO-treated CS to have reduced MS compared with cattle fed unprocessed CS at the same inclusion. Furthermore, Duckworth et al. (2014) reported a 13.4% reduction in YG of finishing steers and an 18.6% reduction in YG of heifers fed CaO-treated CS (20% DM basis) when compared with diets that contained 20% untreated and hydrated CS, 40% MWDGS, and 30% corn (DM basis). Although our reported lack of carcass differences appears to conflict with the findings of Duckworth et al. (2014), it is likely due to the comparison in that trial to 20% untreated CS instead of a corn-based control diet, as discussed above. Of the previously mentioned studies, Russell et al. (2011) was the only study that reported KPH. The KPH results from Russell et al. (2011) are in agreement with our data comparing 5% CaO-treated CS to the control. However, there have been no observed differences in LM area in response to feeding alkali-treated CS among various researchers (Russell et al., 2011; Shreck et al., 2012a,b; Duckworth et al., 2014). There was no effect of dietary treatment ($P = 0.84$) on HCW (Table 3). This finding is consistent with those of Russell et al. (2011) and Shreck et al. (2012a,b). They also noted HCW remained unchanged for cattle fed diets that contained 20% treated CS (DM basis) with 5% CaO (DM basis) when compared with their individual control diets. However, Duckworth et al. (2014) reported a 3.25% reduction for steers and a 5.19% reduction for heifers that were fed 20% CaO-treated CS with 5% CaO (DM basis) compared with cattle fed the untreated, hydrated, and anaerobically stored CS diet (20% DM basis). This effect was explained by the decrease in final BW for steers and heifers that were fed treated CS, as previously discussed.

For this study, there were no benefits observed for combining extrusion with alkaline pretreatments for CS. Cattle fed treated CS consumed less (DM basis), but ADG and G:F in those cattle were similar to those of cattle fed CON. The method of chemically treating and anaerobically storing CS decreased DMI but still resulted in similar feed efficiency, despite the 40% reduction in corn grain being fed in comparison to cattle fed CON. Therefore, all treated CS did successfully replace corn in beef finishing rations when fed in combination with MWDGS without altering ADG and G:F. While interpreting these results, it is important to keep in mind that having few animals on test may have affected the magnitude of the response among dietary treatments because of the variation in ADG and G:F for treated CS diets. Nonetheless, MS, BF, LM area, and YG were unaffected by dietary treatment.

Table 4. Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on total tract apparent digestibility in Exp. 2

	Dietary treatment[1]						
Item	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS	SEM	*P*-value
n	5	5	5	5	5	—	—
Apparent digestibility, % DM							
DM	72.3	72.4	71.1	70.8	73.6	1.31	0.58
NDF	49.3[b]	67.4[a]	65.7[a]	64.7[a]	72.1[a]	3.02	<0.01
ADF	52.6[b]	64.6[a]	66.8[a]	66.3[a]	66.0[a]	2.30	<0.01
CP	71.2	71.6	70.7	71.3	72.4	1.41	0.94
OM	73.8	75.5	74.3	74.3	76.5	1.28	0.56

[a,b]Means within the same row without common superscripts differ ($P \leq 0.05$).

[1]CON = 55% corn and 5% untreated ground CS on DM basis (corn control); BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO; 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded; 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded; 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

Experiment 2

There were no differences ($P \geq 0.56$) in apparent total tract DM, CP, EE, or OM digestibility among dietary treatments. However, apparent digestibility of NDF and ADF increased ($P < 0.01$) when cattle were fed diets containing treated CS rather than CON (Table 5). Duckworth et al. (2014) reported an 11.8% increase ($P \leq 0.05$) in apparent DM digestibility when feeding diets that contained 20% CS, treated with 5% CaO (DM basis), compared with a diet that contained 20% (DM basis) untreated ground CS. However, they reported no differences ($P > 0.05$) in apparent ADF digestibility between the treated-CS diet and their control diet consisting of 50% dry-rolled corn and 15% corn silage (DM basis). Shreck et al. (2013a) reported increased NDF digestibility when feeding treated CS compared with their corn control but no change in DM digestibility. Discrepancies among previous reports in literature are unclear but may be related to the different dietary fiber concentrations, the proportions of corn grain and distillers grains among diets, or the degree to which the physical and chemical nature of CS was affected by the processing method. In the present trial, individual ingredients were analyzed (Table 3). Treating CS with chemicals reduced the NDF fraction by 18% to 20%, depending on whether the material was bagged or extruded before feeding with minimal changes in the ADF fraction, thus reducing the hemicellulose fraction. Results similar to those of CaO treatment were noted by Duckworth et al. (2014). Those authors concluded that the chemical treatment of CS may not just be breaking lignin-hemicellulose bonds but potentially reducing structural carbohydrates to simple sugars. Therefore, most of the differences in total tract digestion may be attributed to increasing ruminal fermentation of the fiber fractions. In addition, Duckworth et al. (2014) also evaluated the in situ NDF digestibility of CS that was treated with 5% CaO (DM basis) and CS that had been hydrated to 50% moisture and anaerobically stored (untreated). Over 24, 36, and 48 h of incubation, they reported NDF digestibility increased by 194%, 97%, and 65% for treated CS compared with untreated CS. These previous findings, corroborated by the current trial, explain, in part, how chemical treatment of CS may improve the apparent total tract digestibility of rations containing treated CS.

There was a time × treatment interaction ($P < 0.01$) for ruminal pH (Fig. 1). Ruminal pH was most acidic for cattle fed the BGCS diet from 0 to 6 h after feeding. These findings are contrary to our original hypothesis. We had hypothesized that alkaline agents would assist in maintaining a more neutral pH of the rumen because of their alkaline nature; however, mean ruminal pH decreased ($P < 0.01$) in cattle fed 5% CaO-treated CS diets, particularly for BGCS, compared with cattle fed CON. These data conflict with the report of Shreck et al. (2013a) that found no differences ($P > 0.10$) in mean ruminal pH for cattle fed diets containing CS treated with 5% CaO (% DM basis) compared with cattle fed the control diet containing 46% dry-rolled corn and 40% wet distillers grains with solubles (% DM basis). However, more similar to the current study, Duckworth et al. (2014) reported a trend ($P = 0.06$) for decreased ruminal pH in steers fed 5% CaO-treated CS at 20% (DM basis) compared with those fed an untreated CS diet (20% CS, DM basis). Studies reporting the effects of feeding CaO-treated CS on ruminal pH have been limited, and results are variable among researchers. This may be attributed to the variance in proportions of VFA, as discussed below.

In the current study, there were no time × treatment interactions ($P \geq 0.24$) for VFA concentrations (Table 6). Mean acetate concentration increased ($P < 0.01$) when cattle were fed treated CS, regardless of

Table 5. Analyzed nutrient composition of individual dietary ingredients fed to steers in Exp. 2

	Dietary ingredient[1]							
Item	MWDGS	Dry-cracked corn	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS	CS	Supplement[2]
DM, %	51.74	85.43	49.88	54.38	81.48	77.09	83.40	89.04
NDF, % DM	30.33	12.53	62.21	58.61	59.93	61.94	78.21	10.46
ADF, % DM	26.23	4.44	50.84	46.96	54.90	54.76	55.25	3.01
Fat, % DM	8.32	3.45	0.45	0.63	0.45	0.40	0.58	2.41
CP, % DM	27.61	8.48	2.46	2.02	2.66	2.81	2.95	4.01
OM, % DM	94.87	98.68	82.28	79.54	81.24	82.86	93.76	63.56

[1]MWDGS = modified wet distillers grains with solubles; BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO; 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded; 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded; 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA). CS = unprocessed, baled corn stover.

[2]Supplement formulated to contain (DM basis) ground corn, 60.76%; limestone, 34.19%; swine trace mineral salt, 2.23% (85% salt, 2.57% Fe, 2.86% Zn, 5,710 mg Mn/kg, 2,290 mg Cu/kg, 100 mg I/kg, 85.7 mg Se/kg); ADEK vitamin mix, 0.22% (680,400 IU vitamin A/kg, 68,040 IU vitamin D_3/kg, 9,072 IU vitamin E/kg, 453.5 IU vitamin K/kg, 3.63 mg vitamin B_{12}/kg, 907.2 mg riboflavin/kg, 2,494.8 mg D-pantothenic acid/kg, 3,402 mg niacin/kg, 29,461 mg choline/kg); Tylan 40, 0.25% (88 g tylosin/kg DM, Elanco Animal Health, Greenfield, IN); Rumensin 80, 0.34% (176 g monensin/kg DM, Elanco Animal Health); Thiamine 40, 0.21% (88 g thiamine mononitrate/kg DM, ADM Alliance Nutrition Inc., Quincy, IL); copper sulfate, 0.11%; fat, 1.69%.

treatment, compared with acetate concentrations from cattle fed CON. This increase in acetate was likely the result of the aforementioned increase in NDF and ADF digestibility. Another possible explanation for the increase acetate concentration for steers fed treated CS may be attributed to the increase in fermentable fiber from chemical treatment. It has been well documented that alkaline treatment of poor-quality forages yields greater fiber fermentation (Chestnut et al., 1987; Gates et al., 1987). Considering that increased acetate concentrations are associated with an increase in ruminal

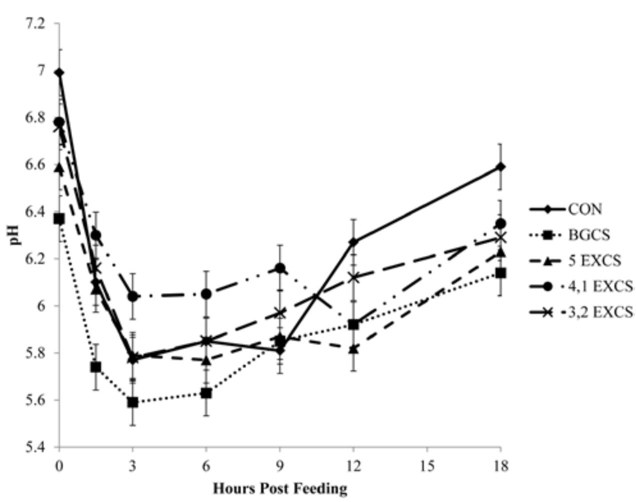

Figure 1. Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal pH change over time in Exp. 2. Steers were fed 1 of 5 dietary treatments: 1) 55% corn and 5% untreated ground CS (CON, diamonds), 2) CS treated with 5% CaO (DM basis) and stored in an Ag-Bag (BGCS, squares; Ag-Bag, A. Miller-St. Nazianz Inc., St. Nazianz, WI), 3) CS treated with 5% CaO (DM basis) and extruded (5 EXCS, triangles), 4) CS treated with 4% CaO and1% NaOH (DM basis) and extruded (4,1 EXCS, circles), or 5) CS treated with 3% CaO and 2% NaOH (DM basis) and extruded (3,2 EXCS, crosses). There was a time × treatment interaction ($P < 0.01$) on ruminal pH. There was a main effect of treatment ($P = 0.02$) on ruminal pH. The error bars reflect the SEM associated with the interaction of treatment × time (SEM = 0.10).

fiber fermentation (Van Soest, 1994), this suggest that our reported increase in acetate concentration was primarily caused by an increase in fermentable fiber from chemical treatment.

There was a significant effect of treatment ($P = 0.01$) for total VFA concentration. Furthermore, there was a time × treatment interaction ($P < 0.01$) for acetate:propionate (**A:P**) ratio. Steers fed CON had the lowest A:P ratio when compared with cattle fed the treated CS diets. At 0 h, the A:P ratio for cattle fed all treated CS diets was greater than the A:P ratio of cattle fed CON, but by 3 and 6 h postfeeding, the A:P ratio for cattle fed treated CS diets had decreased and did not differ from the A:P ratio for cattle fed the CON diet. All of these VFA effects were driven by the shift in acetate, as there was no effect ($P = 0.31$) of treatment on propionate concentrations. Although a previous report (Shreck et al., 2013a) also noted no changes in propionate concentrations when feeding CaO-treated CS, they also did not find any differences in mean acetate concentrations between their CaO-treated CS diet and their control diet (60.3 vs. 57.7 m*M*); however, they did note that VFA concentrations were reduced in cattle fed the treated CS diet compared with those fed the control diet. In their study, VFA samples were measured every 3 h and were composited from 3 to 15 h postfeeding, which may explain the lower total concentrations of VFA compared with those in our study, which measured VFA concentration only from 0 to 6 h postfeeding. The increase in total VFA concentrations among steers fed treated CS diets is a reasonable explanation for the reduced ruminal pH observed in the present trial.

The significant improvements in NDF and ADF digestibility for treated-CS diets and increased concentrations of VFA in Exp. 2 resulted in similar cattle

Table 6. Effect of feeding treated corn stover and modified wet distillers grains with solubles to replace corn on ruminal VFA concentrations over time in Exp. 2

	Dietary treatment[1]						*P*-value[2]	
Item	CON	BGCS	5 EXCS	4,1 EXCS	3,2 EXCS	SEM	T	T × H
n	5	5	5	5	5			
Acetate, m*M*						5.17	<0.01	0.41
0[3]	44.5	74.6	67.2	61.7	62.6			
3[3]	57.5	83.0	84.2	75.3	79.4			
6[3]	59.4	83.8	90.7	84.1	86.7			
Propionate, m*M*						2.81	0.31	0.32
0	18.8	23.7	20.3	16.4	17.0			
3	36.2	40.2	43.8	33.9	40.3			
6	37.9	39.0	40.3	34.1	35.1			
Butyrate, m*M*						1.50	0.05	0.24
0	5.70	13.70	10.0	10.4	10.7			
3	11.4	16.7	14.3	16.1	14.9			
6	10.4	15.2	13.8	16.4	14.3			
Total VFA, m*M*								
0	72.9	116.6	101.4	92.3	94.0	8.10	0.01	0.55
3	110.2	144.6	146.2	129.2	138.5			
6	112.2	143.3	148.7	138.7	140.8			
A:P[4]						0.25	0.06	0.01
0	2.36	3.33	3.46	3.89	3.70		<0.01	
3	1.66	2.17	1.92	2.28	1.97		0.47	
6	1.68	2.22	2.28	2.50	2.49		0.16	

[1]CON = 55% corn and 5% untreated ground corn stover on DM basis (corn control); BGCS = corn stover hydrated to 50% moisture and treated with 5% CaO; 5 EXCS = corn stover hydrated to 50% moisture, treated with 5% CaO, and then extruded; 4,1 EXCS = corn stover hydrated to 50% moisture, treated with 4% CaO and 1% NaOH, and then extruded; 3,2 EXCS = corn stover hydrated to 50% moisture, treated with 3% CaO and 2% NaOH, and then extruded. All extruded corn stover blends were processed using a dual-shafted, encased processor (Readco Kurimoto Continuous Processor, York, PA).

[2]T = main effect of dietary treatment; T × H = interaction of dietary treatment × hour.

[3]Time postfeeding (h).

[4]A:P = ratio of acetate to propionate.

performance when treated CS substituted corn grain, as noted in Exp. 1. It is possible that the increased fiber in the rumen of cattle fed CS diets affected rate of passage and rumen volume, which in turn increased digestibility and VFA concentrations. This may be why the reduction in DMI, noted in Exp. 1, when cattle were fed treated-CS diets, regardless of the treatment, did not ultimately reduce ADG. Cattle fed CaO-treated CS diets likely derived greater amounts of energy from all feedstuffs in the diet. There is currently a lack of information regarding the effects of feeding treated CS on ruminal metabolism and rate of passage, and the discussion generated here is based predominantly on university reports (Russell et al., 2011; Shreck et al., 2012a,b, 2013a,b), rather than peer-reviewed publications. This is an area in critical need of research.

Using various processes, including combined alkaline and extrusion methods, to treat CS decreased DMI without reducing gain or feed efficiency when compared with feeding a conventional diet. We conclude that treated CS successfully replaced corn in beef finishing rations when fed in combination with MWDGS because BF, LM area, KPH, YG, and MS were unaffected. Furthermore, treating CS had no effect on apparent total tract DM or OM digestibility. However, feeding treated CS resulted in improved apparent total tract NDF and ADF digestibility and increased ruminal acetate concentrations, regardless of chemical treatment or processing method. These data suggest processed CS may be a viable substitute for corn grain, especially when fed in combination with distillers grains; however, additional energy and time necessary to extrude CS may not be warranted.

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